AN INVESTIGATION OF THE ROUGHNESS PARAMETER AT OCEAN STATION VESSEL VICTOR UNDER CONDITIONS OF NEUTRAL LASPE

GERLOUS G. MILLER

GRADUATE RESEARCH REPORT

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ABSTRACT

Based upon simultaneous observations of neutral-lapse conditions with the corresponding surface wind value, both for ship Victor, values of the roughness parameter have been computed. For these computations an adjunct relationship for drag coefficient after Kung (1963), is also employed, the latter relationship being primarily statistical in nature. It was found that the roughness length undergoes a variation of ten orders of magnitude as the ratio of the observed surface to geostrophic winds varies through its complete sample range from approximately 0.48 to 0.95.

LIST OF ILLUSTRATIONS

LIST OF SYMBOLS

SYMBOL	MEANING
U_*	friction velocity
H	turbulent heat flux
L	scale length (see introduction)
V	wind speed
V_{20}	wind speed at 20 meter height
V_g	surface (1000 mb) geostrophic wind speed
z	height above surface
z_o	surface roughness parameter
τ	averaged stress vector exerted at sea-air interface
C_D	geostrophic drag coefficient
ρ	air density
k	von Karman constant taken as 0.4
T	dry bulb temperature
T_s	sea surface temperature
Ro_o	surface Rossby number
f	coriolis parameter
θ	potential temperature
C_p	specific heat of air at constant pressure
g	acceleration of gravity
ESSA	Environmental Sciences Services Administration

1. Introduction.

According to the accepted theories on atmospheric turbulence, including those dealing with the Monin-Obukhov similarity principles, there exists a turbulent, atmospheric boundary layer characterized by certain near-constant parameters. These parameters are U_*, the friction-velocity, the turbulent heat-flux H, and a scale-length L defined by

$$L = -\frac{U_*^3}{k\frac{g}{\Theta}\frac{H}{c_p \rho}} \qquad (1)$$

In the present study, where case selection was restricted to neutral-lapse cases at Ship Victor, L is infinite (H=0) and the usual logarithmic profile

$$V = \frac{U_*}{k} \ln \frac{z}{z_0}, \quad k = 0.4 \qquad (2)$$

has been assumed to be valid. Here V is the wind speed at the anemometer-level, which was taken as z = 2000 cm (after some correspondence with cognizant U.S. Coast Guard Officials). No attempt was made to introduce a second statistical degree of freedom, in the form of the <u>datum-level displacement</u>, mainly because accurate wave-heights were not included in the coded data cards for any of the available periods under study.

As is well-known, most operating numerical prediction centers, for example, that of the National Meteorological Center in Suitland, Maryland, make use of average values of the geostrophic drag coefficient, C_D, obtainable from

$$\tau = C_D^2 V_g^2 = \rho U_*^2 \qquad (3)$$

The right side of (3) is dependent upon the roughness parameter z_o (see equation (4) below), grossly averaged, and then taken to be representative of NMC grid points. Operationally, there seems to be little cure for injecting daily deviations of C_D from its seasonal average, but this study was undertaken to investigate the possibility of the existence of such deviations.

2. Selection of the Data.

All data were taken from punched data cards provided by the National Weather Records Center at Asheville, North Carolina. The data cards employed spanned the period 1959 - 1960 at Ocean Station Vessel "Victor" employing only the section 116 (Marine Surface Observations) part of the coded data. Since only 6 to 10 meters of elevation is involved between sea and instrument levels, a neutral lapse would be "isothermal" over this vertical span. However, since both the sea and dry bulb temperatures have, with very few exceptions, been preliminarily rounded off to the nearest degree, the selection criterion for "neutral" was relaxed to the following:

$$T - T_s = \pm 1^\circ F$$

Each of the neutral cases were carefully cited as to date and time, and if the observation time coincided with that of a 00 GCT sea-level analysis in the file of Northern Hemisphere Synoptic Weather Maps covering the same period (1959 - 1960), the particular neutral case was accepted for further computation.

For each case <u>accepted</u>, the shipboard wind speed in knots was recorded from the card file. For the same case the geostrophic wind was carefully read off by measuring the perpendicular spacing between 5 mb

isobars on the synoptically-timed sea-level chart. These measurements were made using dividers; then appropriate distance measurements were converted into a geostrophic wind at the latitude of "Victor" (34^{o}N, 164^{o}E). It was found that use of the geostrophic wind scale on the individual weather maps yielded objectively sound values provided cases where (1) fronts occurred close to Victor, or (2) the isobars in the vicinity of Victor were strongly-curved cyclonically, were rejected.

3. Derivation of the roughness-parameter equation.

First consideration was given to the neutral wind profile applicable at 20 meters:

$$V_{20} = \frac{U_*}{k} \ln\left(\frac{2000}{Z_o}\right) \tag{4}$$

with $U_* = \sqrt{\frac{\tau}{\rho}}$ considered constant in the surface layer. Kung (1963) defines U_* of equation (4) in accordance with

$$U_* = C_D V_g \tag{5}$$

where C_D is his drag coefficient, but is to be interpreted as the square root of that of Cressman (1960). Furthermore, Kung's statistical analysis of U_* resulting from (4) has led to the following empirical result for C_D:

$$C_D = \frac{0.205}{\log Ro_o - 0.556}, \quad Ro_o = \frac{V_g}{f Z_o} \tag{6}$$

It should be noted that Ro_o as defined in equation (6) is a dimensionless parameter describing the large-scale frictional aspects of the boundary layer, and has been called the <u>surface Rossby number</u>.

Combination of equations (4, 5) leads to the result:

$$C_D = \frac{k\left(\frac{V_{20}}{V_g}\right)}{\ln\left(\frac{2000}{z_0}\right)} = \frac{k\,\frac{V_{20}}{V_g}}{2.3026\,\log\left(\frac{2000}{z_0}\right)} \qquad (7)$$

This result, combined with equation (6) yields

$$\frac{0.205}{\log V_g - \log z_0 - \log f - 0.556} = \frac{k\ V_{20}/V_g}{(2.3026)[\log 2000 - \log z_0]} \qquad (8)$$

It should be noted that (8)is valid only for the statistical range of Kung's result (6) and for those conditions under which a neutral boundary layer may be considered to apply. Within these rather broad limitations, the solution for log z_o is

$$\log z_0 = \log V_g - \log f - 0.556 - \frac{(0.205)(2.3026)}{k\,(V_{20}/V_g)}(\log 2000 - \log z_0) \qquad (9)$$

or more specifically, with k = 0.4, log 2000 = 3.30103 and log f = - 4.0886, equation (9) becomes

$$\log z_0 = \log V_g + 3.5326 - \frac{(\log V_g + 0.2316)}{(1 - 0.8474\ V_{20}/V_g)} \qquad (10)$$

Introduce the notation

$$X = \frac{1}{(1 - 0.8474\ V_{20}/V_g)} \qquad (11)$$

and the resulting expression for log z_o finally becomes

$$\log z_0 = \log V_g + 3.5326 - (\log V_g + 0.2316)\,X \qquad (12)$$

Since it is customary to solve for z_o in cm, and f has been expressed in sec $^{-1}$, all wind speeds V_{20}, V_g have been converted from kts to cm sec^{-1} using the conversion factor

1 knot = 51.479 cm sec^{-1}

Equation (12) is the working relationship for the calculations made in this study.

4. Results.

All pertinent boundary layer parameters have listed in Table 1 (see Appendix) for each of the 55 cases which fitted the acceptance criteria. It is noted that V_{20}/V_g varied from a minimum of 0.489 on 1 January, 1959 to a maximum of 0.969 on 25 November 1959. Moreover, V_{20}/V_g appears as a linear variable within the denominator of X. It is therefore evident that the single factor which most strongly affects the value of log z_o is X, which varies from a minimum of 1.708 to a maximum of 5.596, corresponding respectively to the two wind ratios just cited. On the other hand, the contribution of the only other variable in equation (12), log V_g, was relatively minimal varying only by a multiplicative of factor of 0.90 to 1.10 relative to the sample-mean of log V_g.

Thus each value of log z_o was coupled with the simultaneous ratio of X, defined by equation (11). As the above comments suggest, there was an extremely regular tendency for log z_o to decrease with increasing (V_{20}/V_g). This was true both in the 55 individual computations, as well as in class-grouped averages of both log z_o and V_{20}/V_g. The grouping was based on classes of V_{20}/V_g according to the values of these wind ratios in the number ranges 0.45-0.50, 0.50-0.55,........., 0.85-0.90, 0.90-0.95. The corresponding class-mean averages of log z_o were then computed for each wind-ratio class. The paired class-average values were as follows:

V_{20}/V_g	0.45-0.50 0.4893	0.50-0.55 0.5130	0.55-0.60 0.5638	0.60-0.65 0.6323	0.65-0.70 0.6772	0.70-0.75 0.7261
(log z_o) Average	+0.7406	+0.4500	+0.1986	-0.8296	-1.3031	-2.2320

V_{20}/V_g	0.75-0.80 0.7651	0.80-0.85 0.8203	0.85-0.90 0.8624	0.90-0.95 0.9151
(log z_o) Average	-3.4514	-4.5050	-5.7238	-8.6549

The results by class-groups so closely reflected the individual pairings that the final results have been graphed in Figure 1, solely by paired class-averages. The resulting graph essentially presents log z_0 in the functional form

$$\log z_0 = \left(\overline{\log V_g} + 3.5326\right) - \left[\overline{\log V_g} + 0.2316\right]\left(1 - 0.8474\frac{V_{20}}{V_g}\right)^{-1} \quad (13)$$

where $\overline{\log V_g}$ is the sample-mean of the individual values of log V_g. In other words, log z_o has a general simplified form

$$\log z_0 = C_1 - C_2\left(1 - 0.8474\frac{V_{20}}{V_g}\right)^{-1} \quad (14)$$

where C_1 is the constant within the first parentheses of (13) and C_2, that within the bracket of equation (13).

Figure 1 shows that log z_o tends to decrease towards $-\infty$ as V_{20} approaches V_g whereas at the other extreme for $V_{20}/V_g = 0.489$, $z_o = 5.5$ cm, an unusually high value for an oceanic area. Upon exclusion of that class-group V_{20}/V_g with values in the range 0.95 to 1.00 (these were considered unrealistically large for the neutral, steady state case), the mean-value of z_o turned out to be intermediate between the extreme oceanic roughness-values $z_o = 0.1$ cm (for $V_g \geq 10$ kts) and $z_o = 0.01$, for $V_g < 10$ kts, employed by the General Circulation Laboratory of ESSA. Their approach, also empirical, evidently presumes that stronger surface winds and a consequent greater roughness parameter, ensues from the

assumption of a greater geostrophic wind. Such a modeling assumption need not be inconsistent with the results found here, but merely an expression of the relative scopes from which the turbulence problem has been viewed. Some further physical justification of equation (14) is offered in Section 5.

5. Conclusions

It has already been shown in the preceding section that the application of neutral boundary layer wind data chosen purely at random leads to a tenfold variation in Log z_o. However, recent theories of the planetary boundary-layer, specifically those of H.H. Lettau (1961) and Blackadar (1962) for the barotropically neutral atmosphere, but with variable exchange coefficient $K=K(z)$ led to spiral-type solutions with increasing z. One of the main shortcomings of these theories in ascribing proper values of the surface-stress is the assumption of zero acceleration in the large scale wind field. Kung (1963) has given average values of V_{16}/V_g at numerous geographic locations over the oceans, these based upon rather long-averaging periods. When one averages over his summer and winter climatological ratios, the resultant V_{16}/V_g reflects both near-neutral and quasi-steady state conditions. This average value of V_{16}/V_g was 0.68, and extrapolation gives $V_{20}/V_g = 0.70$.

In this study, our median class centered about 0.70, but large deviations in V_{20}/V_g relative to 0.7 did occur, with higher wind ratios reflecting supposedly a smoother air-ocean interface. The interpretation of this surprising result must lie in the use of individual data applied to steady-state theory, which represents improper application of limited theory.

The defects seem to occur in the areas of

(1) the non-inclusion of acceleration terms in the boundary-layer theory.

(2) the slow variation rate of a given sea state, even though the impressed large-scale geostrophic wind undergoes significant change.

Both areas (1) and (2) are interrelated through the basic unknown, the large-scale acceleration, and its feedback rate to the interface. For example, consider our $V_{20}/V_g = 0.5$ relative to steady-state turbulence theories. This was taken to mean that V_g (at gradient level) had responded to an acceleration to which the surface wind was unable to respond, except at much greater lag time. Hence in entering equation (12), X is below average and the resulting log z_o greater than average. On the other hand, an individual case wherein $V_{20}/V_g = 0.90$ compared to the steady-state value of 0.7 indicates that overhead a decrease in V_g had already taken place without a corresponding decrease in V_{20}, due largely to the greater lag-response time at the surface.

The main conclusion of this study is not that of questioning the validity of values of z_o in operational use. Rather, its purpose is to point to areas where the turbulence theory seems to be in need of improvement, especially with regard to the inclusion of unsteady-state conditions in the free-atmosphere, and the difference in <u>response-time</u> in the boundary layer as the interface is approached. The lag time consideration is especially compounded when there is an oceanic interface subject to storm-wave disturbances of short wavelength.

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APPENDIX I - TABLE 1

Table of Variables Needed In Solving
For Log Ƶo, Listed by Case and Date

TABLE 1

Date	T_s(^oF)	T(^oF)	V_g(kts)	V_{20} (kts)	Log V_g	V_{20}/V_g	X	Log z_o
1/2/59	63	64	55	30	3.452	0.545	1.859	+0.135
1/3/59	67	67	50	38	3.401	0.760	2.372	-2.991
1/15/59	61	60	50	31	3.401	0.620	2.107	-0.720
1/19/59	61	61	23	16	3.073	0.696	2.437	-1.449
1/23/59	60	61	47	23	3.384	0.489	1.708	+0.741
1/25/59	60	61	25	22	3.110	0.880	3.937	-6.512
1/26/59	60	60	50	39	3.401	0.780	2.950	-3.784
1/30/59	58	58	28	18	3.159	0.643	2.198	-0.762
2/2/59	59	58	22	20	3.054	0.909	4.355	-7.724
2/3/59	59	60	41	23	3.325	0.561	1.906	+0.080
2/8/59	62	62	29	28	3.174	0.965	5.492	-11.996
2/10/59	61	60	23	22	3.073	0.957	5.288	-10.872
2/15/59	63	63	22	19	3.054	0.863	2.831	-2.714
2/17/59	63	63	14	12	2.858	0.857	3.654	-4.897
2/18/59	64	65	31	20	3.203	0.645	2.207	-0.845
3/3/59	63	63	43	39	3.345	0.907	4.322	-8.579
3/14/59	64	63	30	26	3.189	0.867	2.854	-3.040
3/19/59	63	62	55	50	3.452	0.909	4.357	-9.066
3/23/59	62	61	27	24	3.143	0.889	4.057	-7.015
3/31/59	63	63	22	16	3.054	0.727	2.606	-1.977
4/4/59	59	59	32	22	3.217	0.688	2.398	-1.518
4/5/59	61	61	29	16	3.174	0.552	1.879	+0.309
4/9/59	63	63	23	13	3.073	0.565	1.919	+0.265
4/10/59	64	64	20	11	3.013	0.550	1.871	+0.474
4/11/59	64	64	25	23	3.110	0.920	4.537	-8.518
4/14/59	63	64	26	21	3.127	0.808	3.171	-3.988
4/17/59	63	63	31	30	3.203	0.967	5.549	-12.324
4/18/59	63	63	31	21	3.203	0.677	2.347	-1.325
10/9/59	74	74	29	23	3.174	0.793	3.049	-3.677
10/18/59	72	71	31	27	3.203	0.871	3.817	-6.374
10/20/59	72	73	38	25	3.291	0.658	2.260	-1.140
10/28/59	65	64	38	21	3.291	0.553	1.881	+0.197
10/29/58	69	68	31	27	3.203	0.871	3.817	-6.374
10/30/59	69	68	29	25	3.174	0.862	3.711	-5.931
11/7/59	65	65	27	18	3.143	0.667	2.299	-1.084
11/11/59	71	71	24	23	3.082	0.958	5.311	-10.983
11/17/59	71	71	40	32	3.314	0.800	3.104	-4.157
11/22/59	67	66	29	28	3.174	0.965	5.492	-11.996
11/25/59	69	69	31	30	3.203	-.969	5.596	-12.484
11/27/59	70	70	26	24	3.127	0.924	4.604	-8.802
12/14/59	68	67	17	10	2.942	0.589	1.995	+0.143
12/15/59	68	68	27	22	3.143	0.815	3.233	-4.231
12/16/59	68	69	34	22	3.243	0.647	2.215	-0.922
12/17/59	68	68	33	26	3.220	0.788	3.006	-3.622
12/18/59	69	69	38	33	3.291	0.869	3.789	-6.526
12/20/59	69	69	37	31	3.280	0.838	3.448	-5.296

TABLE 1
(Continued)

Date	T_s(°F)	T(°F)	V_g(kts)	V_{20} (kts)	Log V_g	V_{20}/V_g	X	Log z_o
1/1/60	67	66	38	35	3.291	0.921	4.560	-9.241
1/6/60	66	66	34	30	3.243	0.882	3.964	-6.996
1/7/60	66	65	27	26	3.143	0.963	5.426	-11.635
1/11/60	65	64	32	28	3.217	0.875	3.867	-6.585
1/17/60	66	66	42	30	3.335	0.714	2.533	-2.166
1/28/60	64	63	39	25	3.303	0.641	2.189	-0.900
2/10/60	64	64	24	18	3.082	0.750	2.744	-2.479
2/19/60	64	64	22	21	3.054	0.954	5.222	-10.571
2/22/60	63	64	38	32	3.291	0.737	2.662	-2.553

APPENDIX II

Figure 1 Graph of log Zo Against V_{20}/V_g for Ocean Vessel Victor

Fig.1 Graph of Log z_o against V_{20}/V_g for Ocean Vessel Victor

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13. ABSTRACT

Based upon simultaneous observations of neutral-lapse conditions with the corresponding surface wind value, both for ship Victor, values of the roughness parameter have been computed. For these computations an adjunct relationship for drag coefficient after Kung (1963) is also employed, the latter relationship being primarily statistical in nature. It was found that the roughness length undergoes a variation of ten orders of magnitude as the ratio of the observed surface to geostrophic winds varies through its complete sample range from approximately 0.48 to 0.95.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
ROUGHNESS PARAMETER						
OCEAN VESSEL VICTOR						
NEUTRAL LAPSE						

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